Lunar Dust Effects on Spacesuit Systems: Insights from the Apollo Spacesuits

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Spacesuits in the Lunar "Dust" Environment

- Of all lunar exploration systems, spacesuits have perhaps the largest degree of interaction with lunar soil, including particles in the "dust" size range (< 20 μm).

- Dust effects <u>from</u> spacesuits: Spacesuits are potentially the main "carrier" of lunar soil particles into spacecraft / habitat pressurized environments.

- Dust effects <u>on</u> spacesuits: Spacesuit components will need to remain functional after repeated exposure to lunar soil particles, over extended stays on the moon. Potential negative effects on multiple components and systems

The Apollo Spacesuits: What did we learn?

- Real-time and de-briefed crew reports contain significant mention of lunar dust effects on the Apollo spacesuits (Gaier, 2005)
- Few of these reports were verified by post-mission testing of the suit components themselves.

- One spacesuit was disassembled post-flight to look at lunar dust effects: A7L-series spacesuit worn by Apollo 12 lunar module pilot (LMP) Alan Bean
- All remaining Apollo spacesuits received various degrees of post-mission “cleaning”, and then were assigned to museum “tours” or allocated as museum specimens
- All except Apollo 12 suit are now at the National Air and Space Museum

The Apollo Spacesuits: More to learn

- Even 35 year later, the Apollo spacesuits are viable candidates for post-flight analysis of the effects of lunar dust on spacesuit components and systems
- "Time is our enemy, technology our ally"
- Support next-generation suit development

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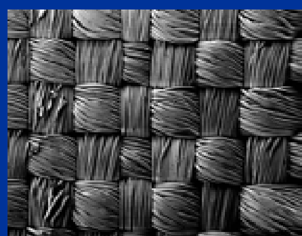
NASDIRT Objectives and Guiding Questions

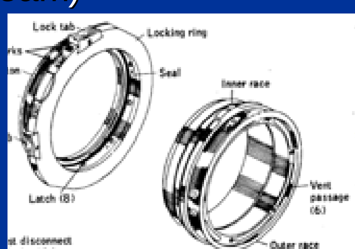
Effect of Lunar Dust On Spacesuits

Spacesuit and Pressure Glove Outer Fabric Assembly (GRC Team)

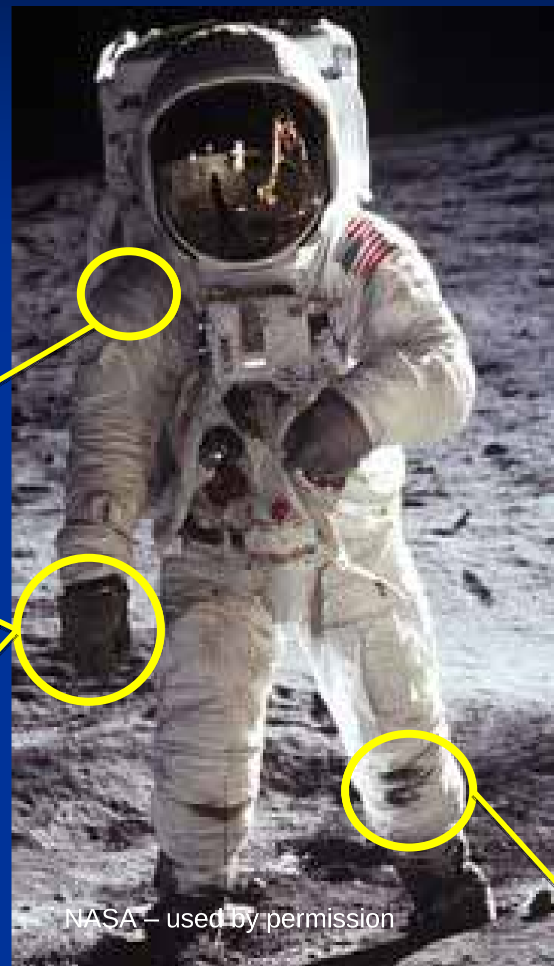
- What is the degree and pattern of fabric wear (fraying, thread breakage)?
- What role (if any) did lunar soil play in causing this wear
- Ultimately, how did the materials “perform”?



Pressure Glove Wrist Rotation Bearing (JSC team)



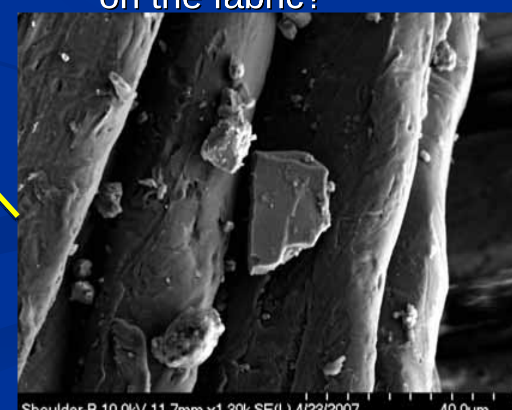
- Use as pressure seal “test case”
- Was lunar soil able to penetrate O-ring assembly and increase bearing wear?



Effect of Lunar Dust From Spacesuits

Spacesuit Outer Fabric Assembly (JSC team)

- What is the size of particles “retained” on outer fabric?
- How do particle types (mineralogy) compare to soil at landing site?
- Does fabric retain some particle types more than others?
- What is particle “loading” on the fabric?



Particle Size Distribution and Mineralogy on Apollo 17 Lunar Module Pilot Spacesuit

- The Apollo 17 spacesuit worn by lunar module pilot Harrison H. "Jack" Schmitt received much less post-mission cleaning relative to other Apollo spacesuits
- It provides an opportunity to sample and characterize lunar soil contamination on the Integrated Thermal Micrometeorite Garment (ITMG) outer fabric.

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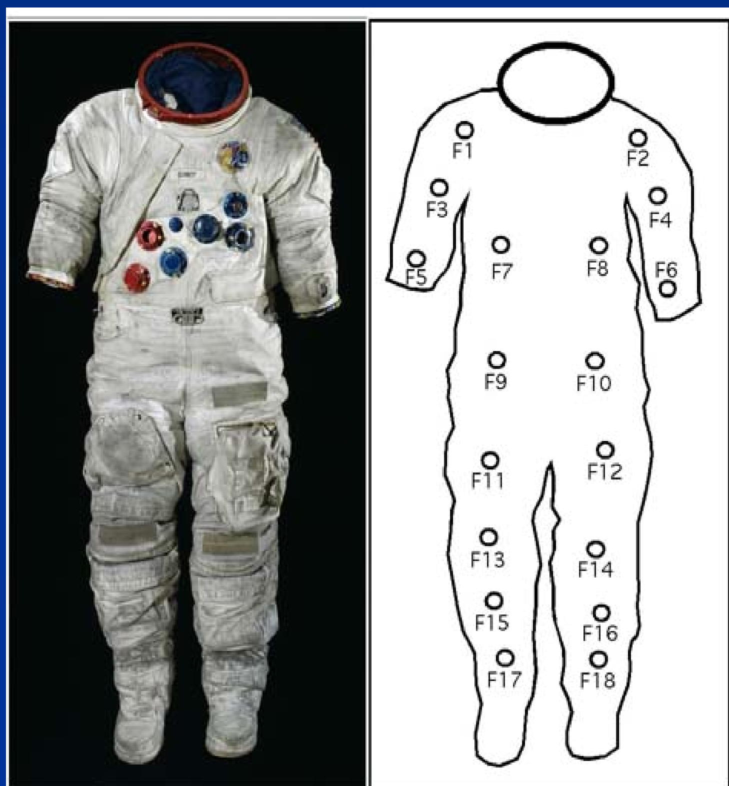
Layer sequence (relative to surface)	Material	Functions
1a	Teflon cloth (T-164 8.5 oz woven Teflon fabric)	Abrasion, flame resistance (only on high-wear areas)
1b	Teflon-coated filament Beta Cloth (Beta 4484)	Abrasion, flame resistance
2	Aluminized Kapton film/Beta marquisette* laminate	Thermal radiation protection
3	Aluminize Mylar	
4	Non-woven Dacron	Thermal spacer
Repeat layers 3 and 4 several times		
5	Rubber-coated nylon ripstop	Contact layer with pressure suit

Non-Destructive Particle Sampling

- Particles on the surface of the outer fabric (woven Teflon® or Teflon-coated fiberglass) were sampled using an adhesive “tape pull” technique adapted from use on space shuttle tiles.



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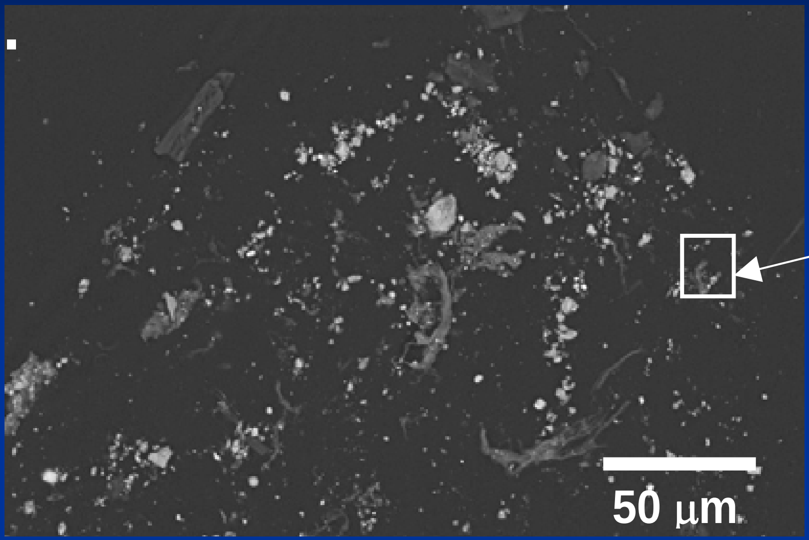
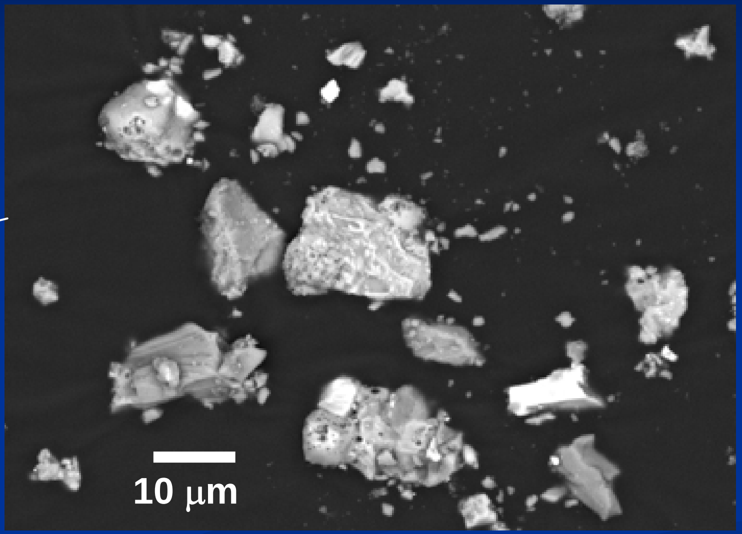
- Particles on the tape surfaces were counted and characterized by analytical scanning electron microscopy (SEM).

Tape Sampling SEM Results

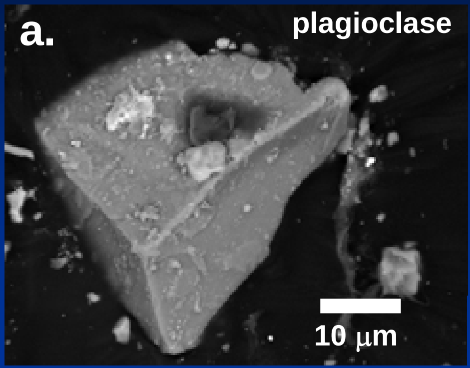


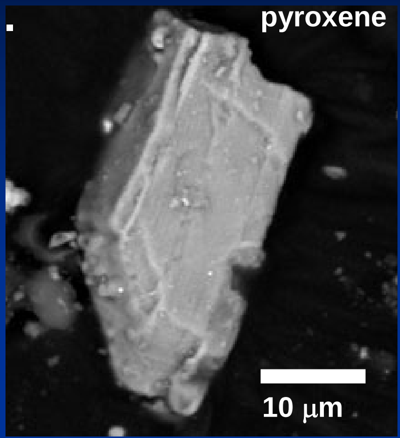


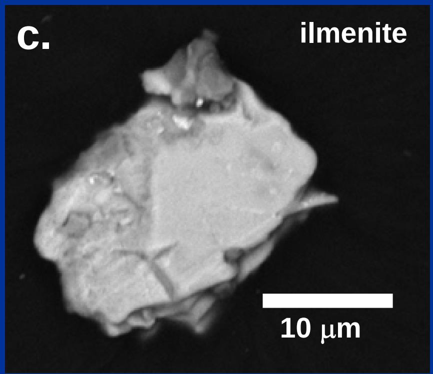
- Tests indicate tape "pull" method consistently extracted 70-80% of adhering particles.
- Particle "types" (lunar vs. non-lunar; mineralogy) determined based on EDS analyses and morphology.
- EDS limited reliable identification to grains > 1-2 μm in diameter.

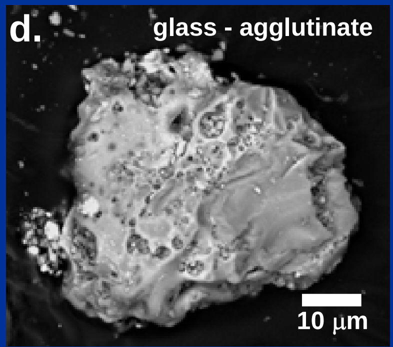
Grain Type Examples

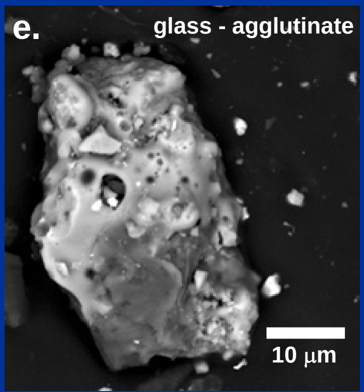
Lunar Particles

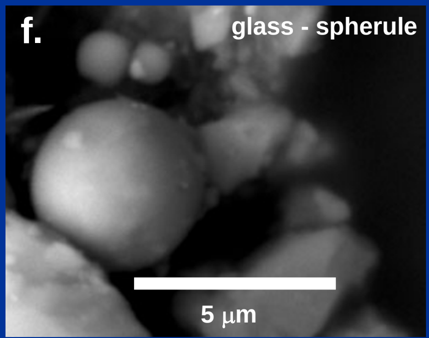




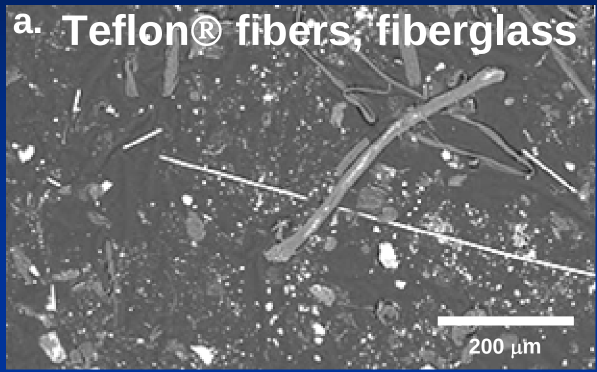


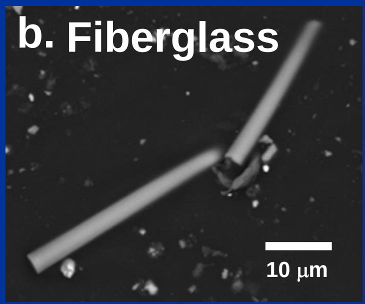


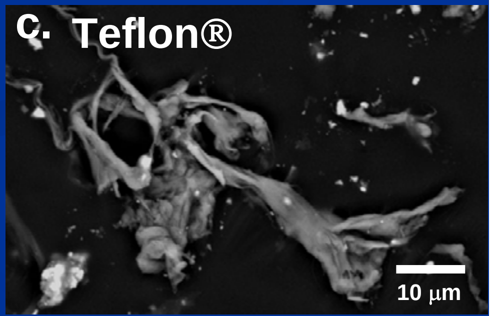


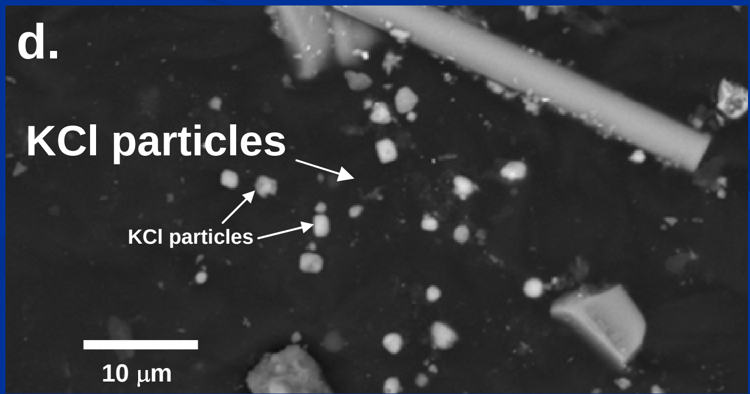


Non-Lunar Particles (“contaminants”)

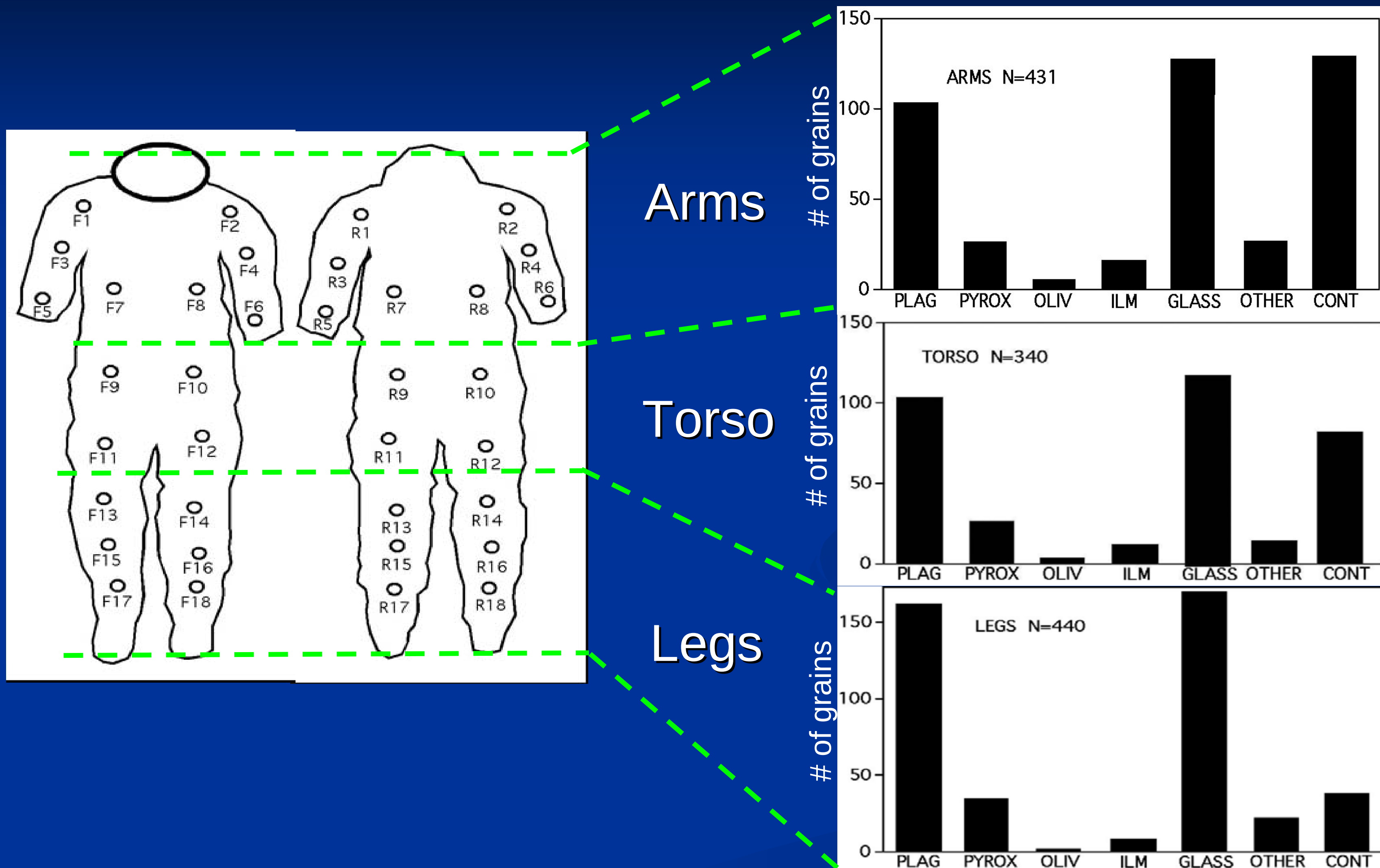




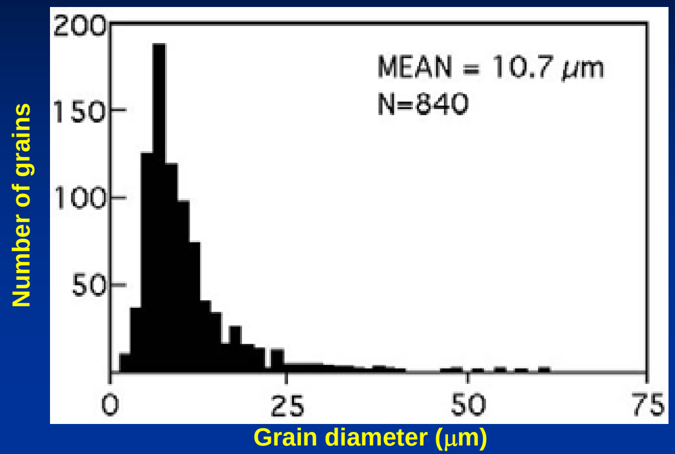


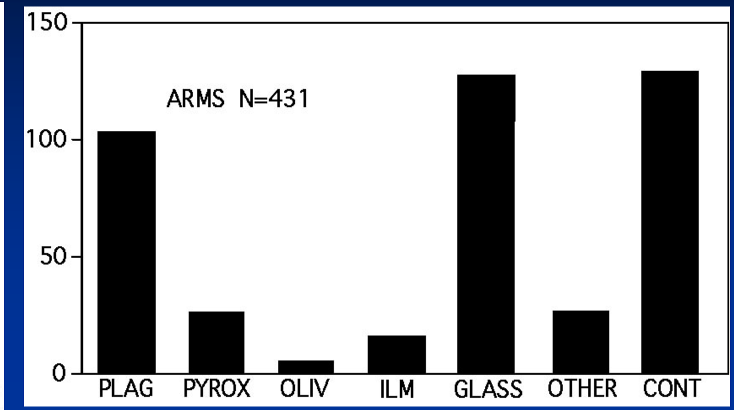


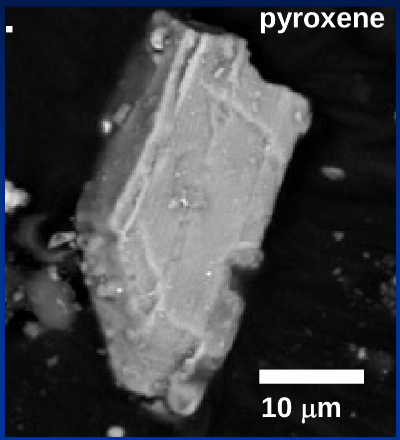
Particle Type Distributions



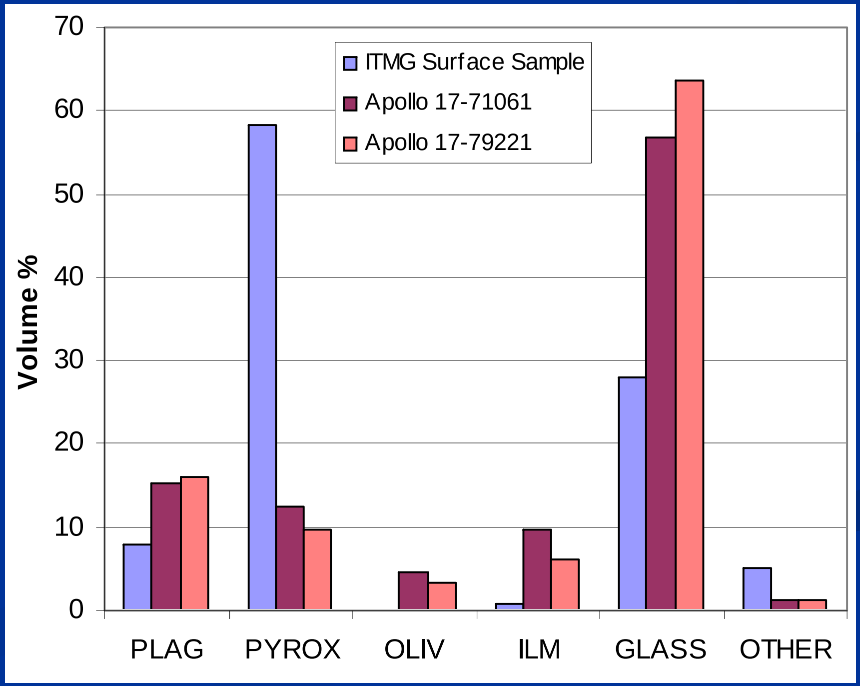
Particle Size Distribution and Modal Mineralogy





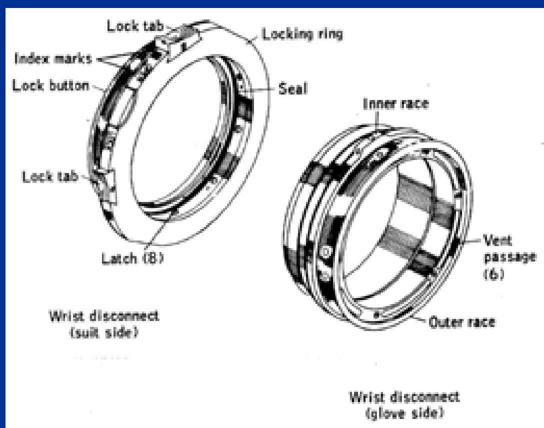


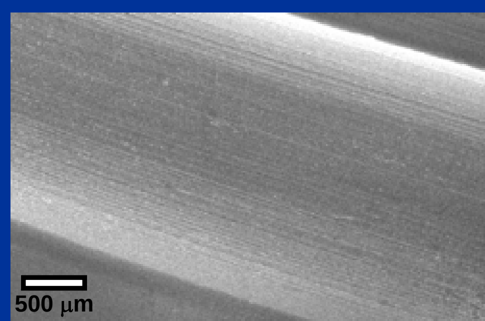
- Processing of SEM images yielded data for size distribution of individual grains based on particle count, as well as “modal” mineralogy based on relative total volumes of mineral phases.
- Pyroxene is less abundant than other phases, based on grain count, but has the highest modal abundances because individual grains tend to be significantly larger than other phases.
- Pyroxene is significantly enriched relative to Apollo 17 soils, while glass particles are depleted.



Glove Wrist Rotation Bearing

- Apollo reports suggested that rotating bearing mechanisms started to operate with increased friction, possibly due to lunar soil contamination. We disassembled and compared the degree of wear on the sealed wrist rotation bearing on extravehicular (EV) versus intravehicular (IV) gloves from Apollo 16 LMP Charlie Duke.



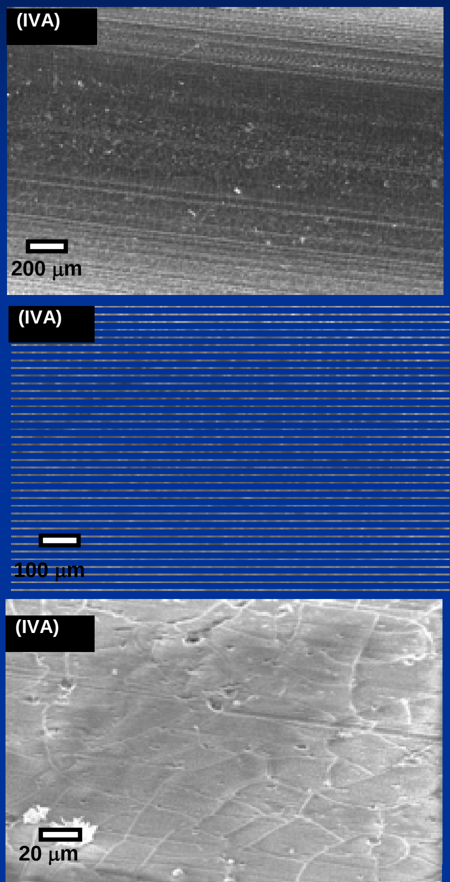


IV Glove

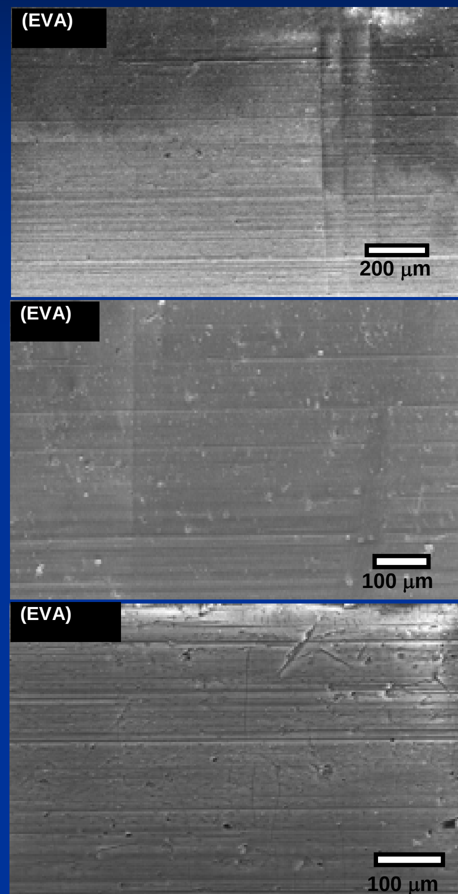
EV Glove

Rotation Bearing SEM

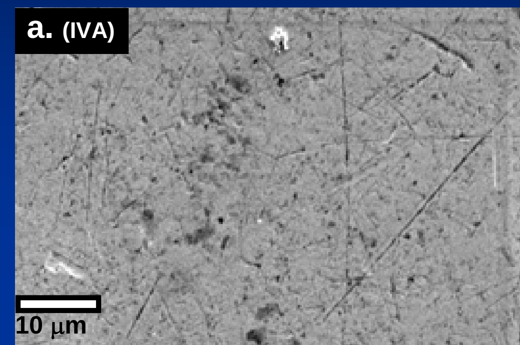
IV Glove

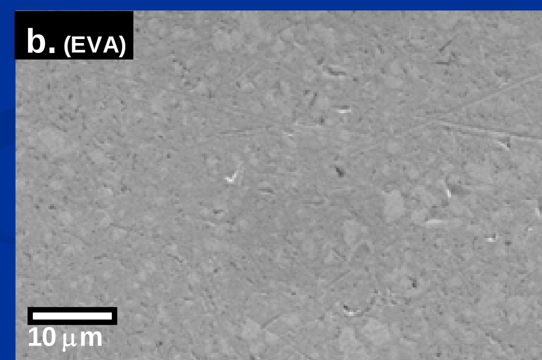


EV Glove



Ball bearing surfaces





- Image analysis of groove and scratch densities suggest grooves are due to original machining, with no increased abrasion in the EV versus IV bearings.

- Ball bearing surfaces also show no differences in amount and depth of scratches

Conclusions

- Quantitative analysis of the size distribution and mineralogy of lunar dust and contaminant particles adhering to the Apollo 17 ITMG was still possible after more than 35 years.
- Particle size distribution had an arithmetic mean of 10.7 μm, with a positive skew to larger particles.
- Recalculation of particle population to a modal basis shows the outer fabric preferentially “selects” and retains pyroxene, but does not retain glass particles.
- There is no evidence that increased wear occurred in the glove wrist rotation bearing surfaces or ball bearings of the EV versus IV gloves.